ATG Spectrum Migration

Response to Telcordia Technologies Comments on AirCell Proposal

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Prepared by:

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1. EXECUTIVE SUMMARY

This technical memorandum/response evaluates the paper titled "Coexistence Analysis for Multiple Air-to-Ground Systems" authored by A.A. Triolo and J.E. Padgett of Telcordia Technologies and submitted to the Federal Communications Commissions (FCC) by Verizon Airfone on June 3, 2004. In the aforementioned document Telcordia provides analyses of the AirCell and Boeing Proposals for the sharing of ATG spectrum (849-851 MHz and 894-896 MHz).

AirCell disagrees with Telcordia's analysis in several critical respects:

(1) Telcordia assumes propagation losses that have no physical basis for both the forward and reverse ATG channels in order to support its conclusions. Specifically, Telcordia assumes that all forward and reverse channels suffer from fading, shadowing, and other losses of the order of 10 dB. While terrestrial cellular channels may suffer from multipath Rayleigh fading and shadowing and obstructions of this magnitude, this is not true for line of sight ATG propagation channels.

(2) Telcordia claims that AirCell has failed to consider the effects of base-to-base station interference, and states that this is a factor that will invalidate the reverse–duplex sharing of the spectrum. AirCell has specified that such interference be controlled by use of uptilted base station antennas and base station site spacing of 5-10 miles, depending upon terrain and antenna heights. Telcordia's limited analysis considers no antenna discrimination between sites (no uptilt) and free space propagation losses. Since the analysis totally ignores the criteria specified by AirCell, the conclusions are entirely unjustified.

(3) By relying upon channel propagation and system implementation assumptions that are in error and/or unnecessarily pessimistic, Telcordia produces analyses of interference for flight scenarios which are also erroneous and which have lead them to erroneous conclusions. In particular, thier introduction of an unjustified 10 dB path loss on ATG paths (but not on aircraft-aircraft paths), coupled with an artificial flight scenario creates a 20 db overstatement with respect to aircraft-aircraft interference.

(4) Telcordia's analysis assumes that every aircraft (cargo, private, small or large passenger) will generate the same amount of voice/data traffic service as large passenger aircraft. This serves to overstate intersystem interference.

(5) Telcordia's analysis overstates the probability of interference from the US Navy AN/SPS-49 air search radar systems in nearby spectrum. We conclude that the interference from AN/SPS-49 radar use in the 902-928MHz band will be a low probability and will also be a localized event. Further, if and when such interference occurs, it is a problem that will impact both the normal and the reverse duplexed channel assignments at similar levels.

In summary, many of Telcordia's arguments are based on unsupported assumptions and/or conjecture. When these factors are stripped away, Telcordia's analysis techniques support the

conclusion that AirCell's proposal provides a viable method for sharing spectrum amongst various service providers in the ATG band.

2. INTRODUCTION

The current plan for the Air-to-Ground (ATG) band (849-851 MHz and 894-896 MHz) uses 6 kHz channels and supports narrowband speech and occasional low bit rate data transmission. Aircraft receive on the lower band and transmit on the higher band, and, at the present time, Verizon Airfone is the only remaining service provider using the ATG band. Current ATG spectrum utilization is neither efficient, no supportive of carrying a broader array of voice and (higher speed) data-centric applications.

AirCell has proposed a scheme which will allow sharing of ATG bands by two service providers. The key concept in this proposal is the introduction of reverse duplexing, in which aircraft served by the second carrier will receive on the higher band and transmit on the lower band to provide adequate isolation between the two carriers sharing the band. Careful base station location selection and site engineering, use of low power transmitters on the aircraft, and the normal minimum physical isolation between aircraft permit two carriers to provide service to large numbers of aircraft. The AirCell document "Evaluation of the ATG Spectrum Migration Concept" presented to the FCC on March 10, 2004 in WT Docket No. 03-103 presents the methodology for this approach as well as verification of system performance through analysis of extensive simulations results.

In response to the aforementioned AirCell document, Verizon Airfone presented the commission with a technical memorandum titled "Coexistence Analysis for Multiple Air-to-Ground Systems" authored by Dr. Anthony A. Triolo and Dr. Jay E. Padgett of Telcordia Technologies, wherein many questions/issues about the original AirCell proposal have been raised. ***The purpose of this document is to respond to questions/issues raised by Telcordia and show where faulty assumptions have lead to erroneous conclusions. In fact, when certain faulty assumptions are corrected, Telcordia's simulations appear to largely support the previously submitted AirCell analysis.***

In Section 3 of this response, we address the comments of Telcordia regarding the AirCell proposal and simulations. In Section 4, we address the Telcordia comments on the effect of Naval Air-Search Radars on the AirCell proposed system.

3. SIMULATION OBSERVATIONS MADE BY TELCORDIA

Followings are summaries of the observations made in Telcordia's technical document and the AirCell responses to them.

3.1. 4-cell square geometry

- ***Telcordia comment:*** *"AirCell assumed a 4-cell square layout geometry for each system, with system 2 rotated 45° with respect to system 1. If this layout is extended to more cells, it appears as in Figure 4 (see Telcordia document [1]), which results in some of the system 1 and system 2 base stations being very close to each other. An alternative would be to use a half-cell offset in each dimension as shown in Figure 5 (see Telcordia document [1]), which can be uniformly replicated over a plane".*

  - ***AirCell Response****:* It is a valid observation that the 4-cell square layout geometry for each system, with system 2 rotated 45° with respect to system 1 extended to more cells will appear as in Figure 4 of Telcordia's technical document [1]. This is because such an arrangement does not produce a tiling of two-dimensional plane [2]. Thus the AirCell simulation results are more conservative than those reported by Telcordia which means that the AirCell proposed system is over-engineered. This over-engineering approach of AirCell is evident from the results reported in Telcordia's verification of AirCell's simulations (see Tables 1 and 2, page 20 of Telcordia's document [1]).

3.2. Base-to-base Interference

- ***Telcordia comment:*** "*Base-to-base interference is ignored on the assumption that base stations of different systems will be separated by a distance exceeding their mutual radio horizon.*".

  - ***AirCell Response:*** AirCell's statement regarding base-to-base interference was: *"Base-to-base cross interference between System 1 and System 2 is essentially zero. This interference is controlled by spacing the two network's respective base stations, System 1 and System 2, more than 5-10 miles apart (terrain and antenna height dependent) and by using uptilted base antenna patterns3 (which are also required to manage own-network multipath)."*

  Telcordia's analysis was based upon free space propagation, with no consideration for the terrain screening/obstruction loss, and with no consideration for the impact of the discrimination provided against the horizon with uptilted antennas. While such an analysis is clearly deficient, AirCell intends to further clarify this situation in a separate filing in the near future.

3.3. Reverse pole point formula

- ***Telcordia comment:*** "AirCell's reverse link pole point formula has a minor error as discussed in Annex B".

  - ***AirCell Response:*** Telcordia's interpretation of quantities in equation (6, pg. 22) of AirCell's document are incorrect. The factor I_{adj} in equation (6, pg. 22) is defined as the ratio of the out-of-cell interference to the in-cell interference. Using, Telcordia's notation, proper expression for I_{adj} can be written as

$$I_{adj} = \frac{I_{oc}}{\sum_{j \neq i} P_j} \tag{3.1}$$

where I_{oc} is as defined on pg. 64 of Telcordia's document.

On the other hand, factor f in Telcordia's document is defined as

$$f = \frac{I_{oc}}{\sum_{j} P_j} \tag{3.2}$$

Therefore, contrary to Telcordia's interpretation, $f \neq I_{adj}$ and equation (29, pg. 66) of Telcordia's document is incorrect.

However, the analysis of the pole point provided by Telcordia is accurate and essentially identical to AirCell's analysis. To demonstrate that this is the case consider following *equivalent* pairs of equations.

Telcordia (20, pg. 64) $$I_{tot} = N + (1 + f)\sum_{j} P_j \tag{3.3}$$

AirCell (6, pg. 22) $$I_{tot} = N + (1 + I_{adj})\sum_{j \neq i} P_j + P_i \tag{3.4}$$

Assuming *K* identical mobiles

Telcordia (21, pg. 64) $$I_{tot} = N + (1 + f)KP \tag{3.5}$$

AirCell (from 3.4) $$I_{tot} = N + (1 + I_{adj})(K - 1)P + P \tag{3.6}$$

Using $I_{tot} = (M+1)P$ (see Telcordia pg, 64), (3.5) and (3.6) transform into

Telcordia $$(M+1)P = N + K(1+f)P \quad (3.7)$$

AirCell $$(M+1)P = N + (K-1)(1+I_{adj})P + P \quad (3.8)$$

When the system operates at high traffic loading, the thermal noise terms, N, in (3.7) and (3.8) can be neglected, which leads to

Telcordia (23, pg. 65) $$K_{pole} = \frac{M+1}{1+f} \quad (3.9)$$

AirCell (9, pg. 23) $$K_{pole} = 1 + \frac{M}{1+I_{adj}} \quad (3.10)$$

Therefore, when I_{adj} is interpreted in a correct manner, equations obtained by Telcordia are identical to AirCell's.

However, the pole point analysis given in Section 4 of AirCell's document is used only as nominal indication of the load that can be served by a single base station. As indicated in Remarks 1 and 2 at the end of the section (pg. 23), these results of the analysis are quite sensitive to the distribution of planes, the value of I_{adj} and the required data rates from aircraft to the ground. Therefore, in the actual simulations all interferences are calculated for any analyzed position of flying aircraft. Based on calculated interferences and aircraft data rates, AirCell's simulator calculates required reverse link transmit power necessary to complete the link.

3.4. Service being modeled

- ***Telcordia comment:*** *"It is unclear what service is being modeled, since speech was used on the reverse link but high speed data with 1xEV-DO (which does not support speech) was used on the forward link. From a mechanical perspective, the reverse link speech simply serves to provide a means of computing the aircraft transmit power."*

    - ***AirCell Response:*** We expect that the majority of the reverse link traffic will be voice (using one or more Voice over IP standards) with asymmetric high bit rate data transactions (consistent with web browsing-type applications) dominating on the forward link. Contrary to Telcordia's assertion, the recently released 1xEV-DO rev A is designed specifically to support low latency applications such as voice, and in fact, there was recently a demonstration of VoIP service over Verizon Wireless' commercially deployed EV-DO service in Washington, DC.[3]

3.5. Aircraft interference from same system

- ***Telcordia comment:*** *"It is unclear how AirCell accounted for the interference to the aircraft from other base stations of the same system. Such interference does not seem to be included in the worst case interference calculations in the section 5 of the AirCell paper."*

    - ***AirCell Response****:* Section 5 of the AirCell paper evaluates the impact of reverse spectrum interference for the forward link. The scenario shown reflects the impact on the forward link under a situation in which there is little intra-system interference from other base stations of the same system, and therefore the impact of intersystem interference from aircraft (using reverse duplex channels) is most evident. This is the worst case situation for inter system interference - if a large number of base stations on the same system are also creating interference, the relative impact of the inter-system interference would be diminished.

      As can be seen, the minor issues raised by Telcordia only demonstrate that the **AirCell proposed coexistence plan analysis is conservative**.

3.6. Idealized link budget

- ***Telcordia Comment:*** *"The link budget assumptions were idealized, assuming perfect propagation with no reflections, no system implementation losses, and perfect power control".*

    - ***AirCell Response:*** There are two main differences between the link budget assumptions of Telcordia and those of AirCell:
        - **Issue 1**: Telcordia allows 2 dB extra link budget for diplexer losses. This is a minor issue as Telcordia own simulation (See Table 1 of Telcordia document [1]) shows that even when a 2 dB diplexer loss is added, AirCell's reported results are conservative (lower performance than those reported by Telcordia). In other words, even if operators choose to use diplexers (rather than using separate transmit antennas), Telcordia's analysis shows that AirCell's

proposal provides a viable solution for coexistence of two service providers in the ATG band.

- **Issue 2:** In addition, Telcordia allows 10 dB additional budget for "*non-idealities in propagation and implementation, including the effects of multipath and variations in antenna gain due to tolerance in the tilt and horizontal orientation*". The justification for the value is "*Airfone's operational experience*", as indicated in "Private communications with Verizon Airfone" (see page 15 of Telcordia's document [1]).

  When trying to justify what issues are covered in this additional implementation link margin, Telcordia states that (see pages 41-42 of Telcordia's document) *"A 10 dB system implementation/ fading margin was assumed as is typically done during the planning of the air to ground network…. This margin is included to take into account antenna mounting inaccuracy, higher than expected cable loss, fading due to blockage, and other unexpected design losses. This 10 dB seems reasonable considering all of the unknown factors that come into play when designing a system that needs to operate robustly*."

The details of Airfone's rationale for a 10 dB margin are of course not clear from the record provided. It appears that it may be a system planning guideline that might be useful for determining worst case link performance – defining the extreme cases under which a link will still operate satisfactorily. If so, use of such a factor for simulation of all links operating under average conditions would be entirely inappropriate.

AirCell expects that all base stations will be selected, engineered and implemented in a manner that will support the typical performance described in its March 10, 2004 document:

- A 3 dB margin has already been accounted for the cable loss and this estimate is extremely conservative. Thus, there should be no need to account for additional cable losses in the link margin by allowing for excessive cable losses.

- Paths which are obstructed should be very atypical when sites are properly located to provide clearance above the surrounding terrain/buildings.
- Commercially available base station antennas with uptilt should be selected and aligned to provide protection against destructive specular reflections. The uptilt will provide discrimination against specular reflections which might otherwise cause signal losses (and will also provide a useful amount of discrimination for signals from any nearby reverse-duplex base stations.)
- Paths to aircraft will be nearly always line of sight, and variations in the received signal strength will be small (similar to those of line of sight microwave systems). Eb/No objectives used in the simulation already include an allowance for such signal fluctuations.

We note that even in terrestrial cellular networks where fading, shadowing and blockage are very common, the entire system implementation link margin may be 10 dB, including cable and diplexer losses (see for instance 3GPP Working Group, 1xEV-DO Evaluation Methodology, Qualcomm Inc, C30-DOAH-2003, pages 47-48). It is not clear to us how Telcordia/Verizon might require a 10 dB system implementation link margin in addition to a total of 5 dB cable and diplexer losses in the much more predictable ATG propagation environment.

In summary, AirCell sees that adding any margin similar to Telcordia's M_{sys} value would produce a very misleading simulation of expected system performance.

3.7. Simulations limitations

- ***Telcordia Comment:*** *"The simulations considered a very limited (and somewhat artificial) case consisting of a low-rate, low-power speech-only reverse link and a high rate, high power, data-only forward link. The average reverse link rate is 48 kb/s per aircraft under AirCell's model, or a total of 144 kb/s per cell (or sector) for the 75% loading case. In contrast, the average forward link rate seems to be on the order of more than 1Mb/s."*

  - ***AirCell Response:*** As discussed previously, we expect that the majority of the traffic will be voice traffic which is generally symmetric with respect to traffic on the forward and reverse links. Data traffic is expected to be very asymmetric, as is typically observed with Internet applications such as web browsing applications. In such applications, the reverse link traffic consists of mainly short packets corresponding to web browsing requests and the forward link carries most of the traffic and therefore needs to accommodate higher data rates. AirCell's simulation is consistent with these expectations, and is reflected by the characteristics noted by Telcordia.

3.8. Simulation Sensitivity Analyses

- ***Telcordia comment:*** *"No sensitivity analyses were performed to determine the interference impact under other sets of conditions." Telcordia then suggests a sensitivity analyses that includes "the effects of imperfect conditions" and accounts for "higher speed reverse link transmissions".*

  - ***AirCell Observation:*** In order to put our response in focus, it is useful to first review what exactly Telcordia refers to as "the effects of imperfect conditions" (page 25 of Telcordia's document):
    - Telcordia assumes M_{sys} = 10 dB to account for imperfect channel conditions (page 25 of Telcordia document),
    - A random grid offset between the two systems versus a fixed half-cell offset,
    - Fixed aircraft altitude (35000 feet) versus a variable altitude,
    - Approximation of the outer cell same-system forward link interference as a constant versus calculating it for each case.

***Telcordia comment:**: "As can be seen, the factor which seems to make the most difference is the randomization of the offset between the grid cell of the two systems. The net effect of all the approximations is to increase the outage probability somewhat, but the impact on the average forward link rate is fairly small."*

  - ***AirCell Response:*** We have previously refuted the use of 10 dB for implementation margin (please see pages 9 and 10 of the current document).

    In no practical scenario is it likely that the offsets between the grid cell of the two systems is totally random as assumed in Telcordia's simulation, and the other simplifications may limit the generality of their simulation. However, it is very interesting to note that, once the impact of the 10 dB system implementation margin, M_{sys}, is ignored it is clear that **Telcordia's own simulation demonstrates that AirCell's proposed system achieves**

acceptable performance for the operation of two systems in the ATG band. (Refer to Table 1 and Figure 13 of the Telcordia document.)

3.9. Air traffic Density

- ***Telcordia position:*** Telcordia represents that it intends to simulate reverse-duplexed systems under "Real World" conditions (see Telcordia's document Page 31). The use an approximation base upon 4,000 commercial aircraft in service, of which 60% are in the air at any time. Additionally, they assume that 20% of 8,000 private aircraft are in the air at any time, leading to 4000 aircraft that could be equipped with an ATG communication system.
  - ❑ ***AirCell Response:*** In determining the load on the networks under this "Real World" scenario Telcordia assumes that every aircraft (cargo, private, small or large passenger) requires the same amount of voice/data traffic service as a large passenger aircraft. This unrealistic traffic assumption is then used throughout their analysis to arrive at Telcordia's erroneous conclusions in computing performance of the proposed reverse duplexed system.

3.10. Simplified Interference example

- ***Telcordia position:*** Telcordia considers three aircraft flying within 5 miles of each other in the same direction, with System Two aircraft flying at 145 and 155 miles respectively, and System One aircraft flying at 150 miles from the airport. This example is intended to illustrate that *"it is possible then, to experience poor service quality, or outage, along an entire flight path."*

  - ❑ ***AirCell Response:*** The unjustified system implementation link margin of 10 dB is again used to force the aircraft transmit powers at least 10 dB higher than those computed by AirCell. When this factor is eliminated, the SINR for this scenario, which Telcordia acknowledges is likely to be infrequent, is found to fall within the operational range of the system. Further, we note that the distance used between the aircraft and their serving cells is ~150 miles, well beyond the cell radius of 100 miles used in the AirCell simulation.
    Aircell stands by its simulation results, which focus on the impacts of aircraft-aircraft interference and which ***clearly shows that aircraft- to- aircraft interference is a non-issue under AirCell's plan.***.

3.11. Mobile Terminal Power

- ***Telcordia comment:*** *"AirCell's analysis artificially constrains the maximum aircraft transmit power to two-tenths of a watt (equivalent to a single cellular or PCS handset), resulting in the understated aircraft-to-aircraft interference potential it".*

- ***AirCell Response:*** It is well-known that in any CDMA system, there is a level of transmit power beyond which only very meager further system gains can be realized and by increasing the transmit power beyond that limit, the interference is also proportionally increased which eliminates the gain from increasing the transmit power. AirCell's simulation shows this limit is just about 200 mW per aircraft. It is true that this corresponds to the limit on the maximum transmit power of a handset, but this is not a negative consequence at all. On the contrary, this is very desirable, the low transmit power requirements allows a **relatively inexpensive hardware implementation** for aircraft (compared to 1xEV-DO base stations), and also limits the electrical power that must be provided from the aircraft power supplies.

3.12. EV-DO Latency

- ***Telcordia comment:*** *"Aircell does not explain how this comports with the use of 1xEV-DO technology (which has a latency too high for speech) on the forward link." (see the footnote of page 6 of [1])*

    - ***AirCell Response:*** Revision A of 1x-EVDO has much lower latencies than the revision 0; in fact well within the range of latencies that support speech.

In summary, the major issues raised by Telcordia are without merit. In fact, once the unwarranted features of Telcordia's analysis are factored out, it can be concluded that they also have demonstrated that AirCell's proposed coexistence plan is robust in a variety of scenarios.

4. Effects of Naval Air-Search Radars on Reverse-Duplexed Aircraft Reception

- ***Telcordia comment:*** *"It is … reasonable to expect that the interference from the AN/SPS-49 will be a much more common problem for reverse-duplexed aircraft than it currently is for ATG base stations receiving in the 904-896 MHz band and will have a deleterious effect on any such system.*
    - ***AirCell's Response:*** We note that Telcordia's document failed to address two major points regarding this problem.

      Firstly, there is an *extremely low probability of interference* from the adjacent channel AN/SPS-49 air search radar systems. This low probability arises from the following factors:

- Air-Search radar is typically pointed towards the sea.
- Typically, ships turn off their AN/SPS-49 radar about 200nm from the shore.
- Even if the interference is present, it is localized in space (geographic regions) and time (it is not present throughout the year)
- If AN/SPS-49 radar is turned off before 200nm (230miles) from coast, flights flying more than 20 miles inside coast at cruising altitude (have about 250mi radio horizon) will not have much interference. If radar is not turned off at 200nm, some flights that fly at lower altitudes may not be affected.

As stated in an FCC Public Notice, (a document also referenced by Telcordia), "*Generally, AN/SPS-49 emissions are directed seaward to reduce interference to shore locations. However, during Fleet exercises in littoral waters (typically conducted outside of 25 nm from the coasts), the AN/SPS-49 emitters* ***may be briefly*** *closer to the coasts (i.e. launching and/or recovering aircraft)"* [4] **(emphasis added by authors of this document)**

Secondly, if and when the ships come closer to the shore, they might operate the AN/SPS-49 radar up to 25nm from the coast. In that rare event, comparable interference is likely for both carriers using the cross duplexed spectrum.

- If the radar is not turned off at 200nm and operates up to 25nm from the coast, interference problems at the current Airfone BTS (receiving in 894 to 896MHz) could be just as severe or even worse compared to the interference problem at an aircraft in the reverse-duplexed scenario. Looking at Airfone's site locations from Telcordia's document, there appears to be multiple sites along the coast. Let us assume they are 20 to 100 miles from the coast. Path loss can be expected to be 146 to 158dB (with 30dB/decade and 95dB 1-mile intercept). With 114dBm transmitter and 30 to 60 dB spectral rolloff, received power at the BTS will be -62 to -104dBm (45dB to 3dB above noise floor). Assuming BTS can transmit at least 20dB extra power compared to a mobile (aircraft), the S/N at the Airfone BTS will be approximately the same or sometimes worse than S/N at the aircraft in the AirCell scenario. In addition, all aircraft served by that BTS will be equally affected whereas in the AirCell case, it is possible that some aircraft will either not be impacted by the radar, depending upon their location and altitude.

- If Telcordia's reference document for radar emission spectral rolloff is to be used as a guide, it suggests only 10dB additional rolloff over the 45MHz separating the two ATG bands. Interference power from radar will be 8 to 38dB above the noise floor at the aircraft causing nearly as severe a problem for aircraft using the lower band for the uplink.

Noting that Airfone (and other ATG carriers) have operated without significant impact from the AN/SPS-49 radar, our conclusions are quite contrary to Telcordia’s speculation. That is, **use of the radar system in locations is a low probability and localized event; and if and when it happens, it will be a problem that is comparable in magnitude for systems using either of the two channel sets proposed.**

5. REFERENCES

[1] Anthony A. Triolo and Jay E. Padgett, “Coexistence Analysis for Multiple Air-to-Ground Systems”, Telcordia Technologies Inc., June 3, 2004.
[2] J. H. Conway and N. J. A. Sloane, “Sphere Packing, Lattices and Groups”, Spring Verlag Inc., 2001.
[3] Heather Forsgren Weaver “Vonage exec demos VoIP over EV-DO technology”, RCR Wireless News, June 08, 2004
[4] FCC Public Notice, DA 98-2394, November 25, 1998, pp. 3-6.

6. BIOGRAPHIES:

Vahid Tarokh received his PhD in Electrical Engineering from the University of Waterloo, Ontario, Canada in 1995. He worked at AT&T Labs - Research and AT&T Wireless Services until August 2000 as member, principal member of technical staff, and finally, the head of the Department of Wireless Communications and Signal Processing. In September 2000, he joined Department of Electrical Engineering and Computer Science at MIT as an associate professor. Since July 2002, he has been with Harvard University, where he is Gordon McKay Professor of Electrical Engineering and Vinton Hayes Senior Research Fellow within the Division of Engineering and Applied Sciences.

Dr. Tarokh is responsible for a number of inventions, most notably his invention of *Space-Time Coding* (jointly with Seshadri and Calderbank). He has also worked on a number of different research areas, with his current research interest in the area of networking, in particular the design of efficient network protocols, wireless networks, and algorithms for scheduling and switching.

Dr. Tarokh is on the list of the "***Top 10 Most Cited Researchers in Computer Science***" compiled by the ISI Web of Science. He has also received a number of awards including the ***Gold Medal of the Governor General of Canada 1995***, ***IEEE Information Theory Society Prize Paper Award 1999***, ***The Alan T. Waterman Award 2001*** and was selected as one of the ***Top 100 Inventors of Year (2002)*** by the Technology Review Magazine. In 2003, he received an ***honorary D.Sc.*** from the University of Windsor.

Anand Varadachari is the President of Simma Technologies Inc. a technology and management consulting company that he founded in 2001 which is focused primarily on the wireless telecom industry. During 2002 and 2003, Mr. Varadachari also served as the Vice President of Business Development and Sales, and Vice President – Professional Services Group at ISCO International, a wireless equipment manufacturer based at Mt. Prospect, IL. Before that, Mr. Varadachari was with 3Com Corporation as Director of Strategy and Business Development in the Internet Communications Division. He has also held various engineering positions at Ameritech Corporation (1994-1999) as Director of Advanced Technology, Manager of RF Design, and Systems Engineer in its wireless business unit. Mr. Varadachari spent five years (1990-1994) with Telephone & Data Systems, a diversified telecommunications company, in various engineering and marketing roles. Mr. Varadachari has an M.B.A. from University of Chicago and M.S. in Computer Engineering from Iowa State University.